PRECISION MEASUREMENT

BY

W. H. FOSTER, M.I.E.I. A.M.I.Prod.E.

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PRECISION MEASUREMENT

The basis of measurement in Great Britain is "The Imperial Standard Yard", the distance between two finely scribed lines on gold plugs let into a bar of alloy metal.

Copies of the Imperial Standard have been made and are periodically compared with the Imperial Standard, similarly, what we might call our working standards are periodically compared with these copies or sub-standards.

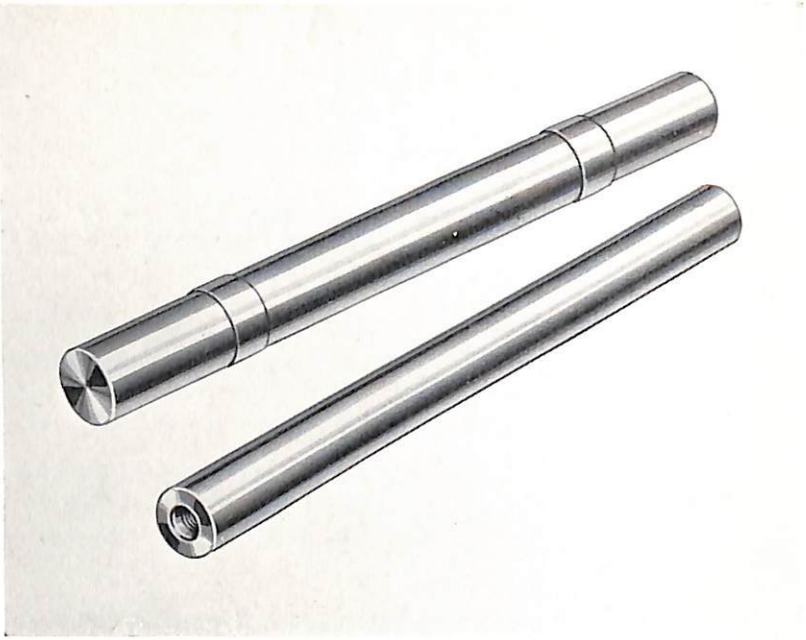
The length of the Imperial Yard has for many years been measured by Interferometry and its length compared with that of the International Prototype Metre by the same methods.

These lengths have been very accurately established in terms of certain radiations of the spectrum under specified conditions and the results of these measurements have shown the metre to be stable and the yard to be slowly decreasing in length. The decrease in length, although small, is very significant when accurate measurement is concerned and difficulties for the precision engineer were increased by the fact that the United States and Canada related their Yard to the Metre, each accepting a different basis for the relationship.

This resulted in the American Inch being nearly 4 millionths longer than the English Inch, with the Canadian Inch falling about midway between.

The Imperial Standard Yard remains our Standard for all trade purposes, but it was internationally agreed in 1959 that for all scientific and technological purposes the Inch would be related to the Metre on the basis that 1 inch is equal to exactly 25·4 mm.

The "Natural Standard" of light wavebands does not suffer the hazards of damage, wear or change of structure of a physical standard and can be used anywhere at the same time. It is used as our Engineers' Standard for the measurement of Reference and Calibration Grade Slip



Inspection and Workshop Length Bars.

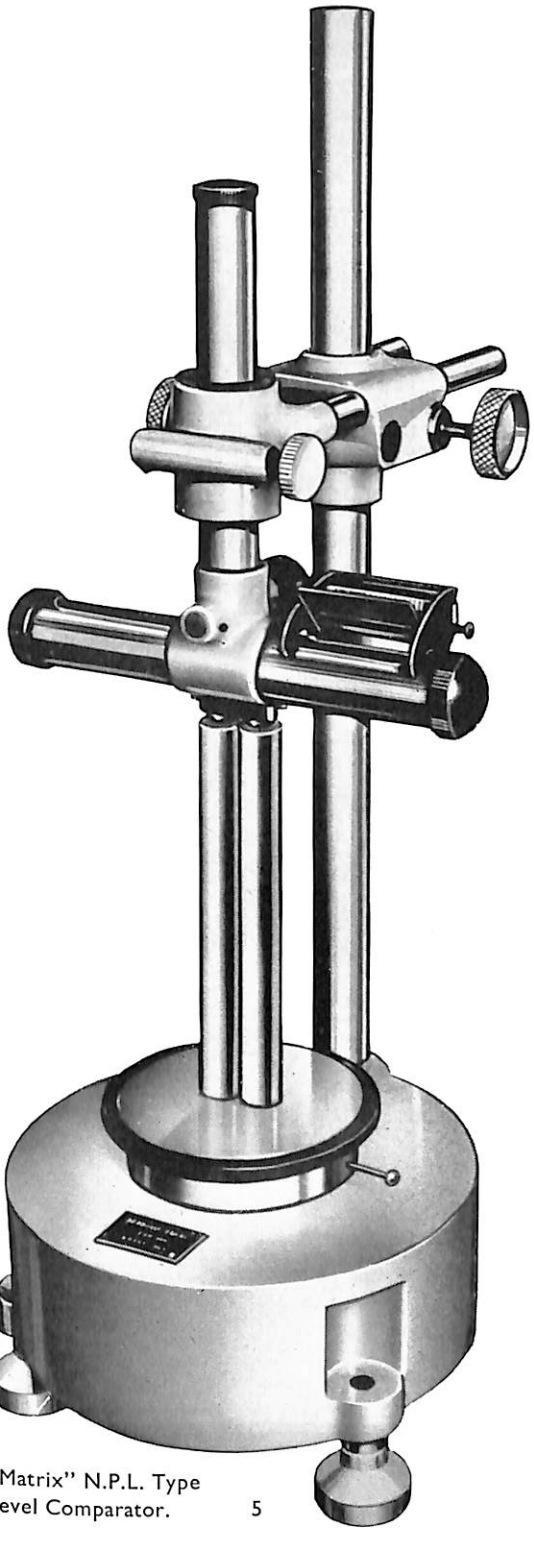
Gauges. The process is however lengthy and requires great care and consequently the lower grades of accuracy are measured by comparison with Standards calibrated by interferometry methods.

Certain measuring instruments and machine tools such as jig boring machines make use of line standards graduated on either metal or glass and calibrated against the copies of the Imperial standard by means of microscopes.

The line standard is not however extensively used in the engineering industry, what is known as the End Standard being most commonly used.

A 36″ end standard can be derived from the line standard in a comparatively simple manner and its size determined to a high degree of accuracy.

We can then make two standards of 18″ identical in length, or three standards of 12″ identical in length making adjustments to them until they are equal in length to the



"Matrix" N.P.L. Type
Level Comparator.

36″ standard plus or minus its known error. Standards that are 9″, 6″ or 4″ in length can then be produced in a similar manner thus building up a set of Standards for determining the size of Reference, Inspection or Workshop grade end Bars by comparative methods.

Measurements of size of end standards are made by comparing the master and test bar under what is known as the Level Comparator, taking great care to ensure that temperature conditions are stable and giving the bars ample time to settle down after handling.

This Comparator was designed at the National Physical Laboratory, and is chiefly used for checking end bars and the larger slip gauges. It consists of a sensitive level mounted on a small plastic block to which two balls are attached, the unit being mounted in a protective case that

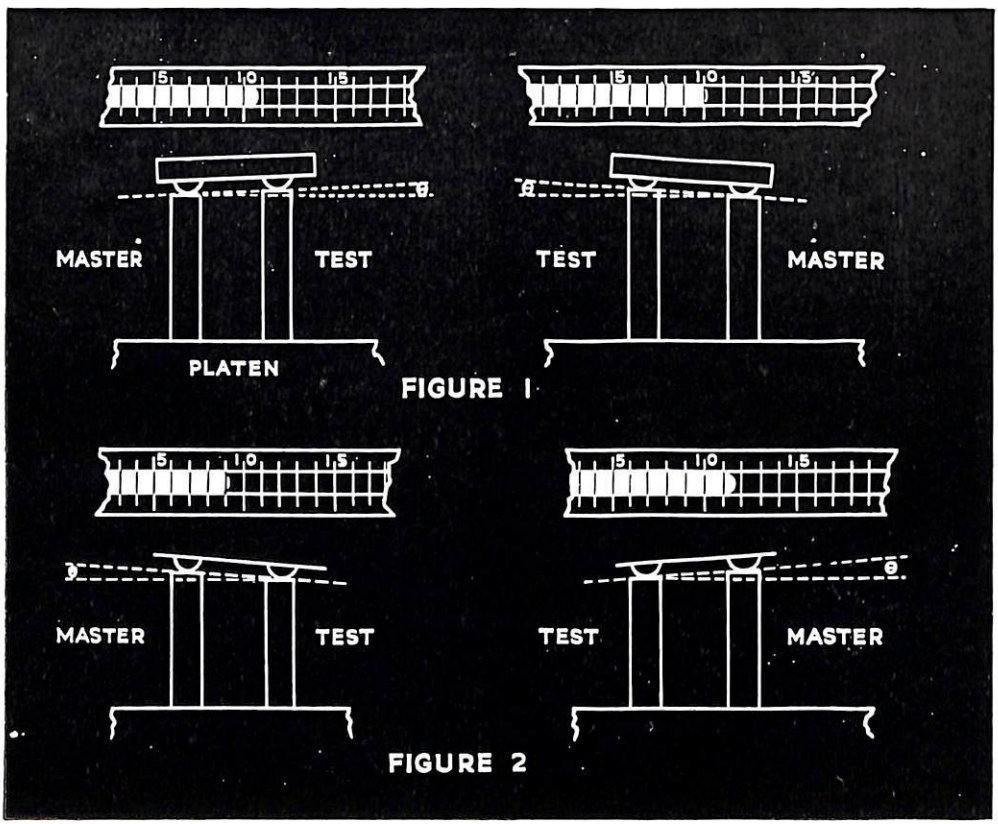


FIGURE 1

FIGURE 2

can be moved up or down a pillar fixed to the base. For long bars it may be found more convenient to use a wall fixing type instrument, but it is essential that the wall is free from vibration.

The upper side of the base is machined so as to leave a circular bearing face about 5″ in diameter and $\frac{5}{8}$″ wide, this face being lapped flat to one or two millionths of an inch. A hardened steel platen, ground and lapped flat and parallel to the same degree of accuracy, rides on this face, and the gauges to be compared are wrung on to the top surface of the platen in such a position as to be under the balls of the level.

The level housing is lowered until the balls make contact with the gauges, lifting the level clear of its case, and the position of the bubble is read against a scale attached to the casing. The scale is marked out so that one division corresponds to a tilt of ·00001″ over the spacing of the balls.

Having recorded the reading, which we will assume to be 10·8 divisions, the level is lifted clear of the gauges and the platen rotated through 180°. The level is again lowered and a second reading taken, which we will assume to be 10·2 divisions.

From Fig. 1 it will be seen that taking the left-hand gauge in the first position as our "Master" of known size, the difference in the level readings corresponds to a tilt of 2 ø or twice the error of the gauge, which in this case shows the gauge under test to be ·000003″ larger than the "Master". In the case of Fig. 2 the test gauge would be $\frac{11{\cdot}6-9{\cdot}2}{2} = 1{\cdot}2$ divisions smaller than the "Master" or —·000012″.

The parallelism of the faces of the test gauge may be determined by wringing the gauge to the centre of the platen and taking successive readings of the level at various angular positions with both ball feet on the gauge.

The flatness of the measuring faces may be checked by the careful application of an optical flat.

Slip Gauges, other than Reference or Calibration grade are checked by means of the "Millionth" Comparator originally designed by E. M. Eden at the National Physical Laboratory.

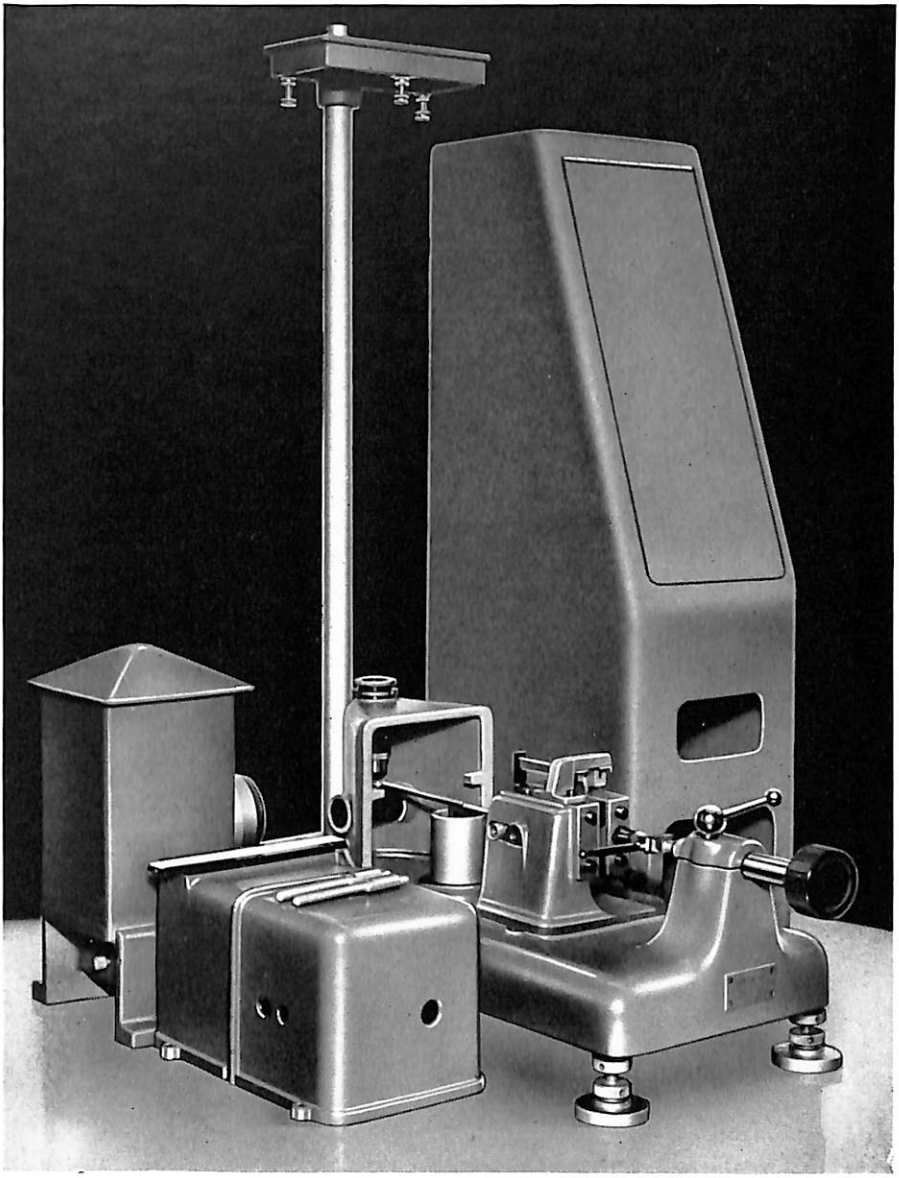
The "Millionth" machine achieves a very high magnification by means which are partly mechanical and partly optical. By employing a spring steel strip mechanism and a lever a magnification of about 350 X is achieved, and this is stepped up to about 20,000 X by a lens and mirror projecting an image at the end of the lever on to a scale. The divisions of the scale are approximately ·2″ apart, each one representing ·00001″.

The measuring contacts consist of a steel ball on one side, and a group of three steel balls in triangular formation on the other, which eliminates many of the difficulties that would arise if plain parallel faces were used.

Flatness and parallelism of slip gauges are best checked as a combined operation on the Interferometer, which has a base and platen similar to the Level Comparator, but an optical system replaces the level. The instrument was originally designed by the National Physical Laboratory, and enables flatness and parallelism of lapped surfaces to be determined to a high degree of accuracy.

The "Matrix" Interferometer is operated by means of monochromatic light obtained from a mercury vapour lamp, the wavelength of which is closely ·00002″.

When such light is passed from the surface of an optical flat which is inclined at a small angle to a reflecting surface, a series of dark bands are seen recurring every half wavelength of the light.



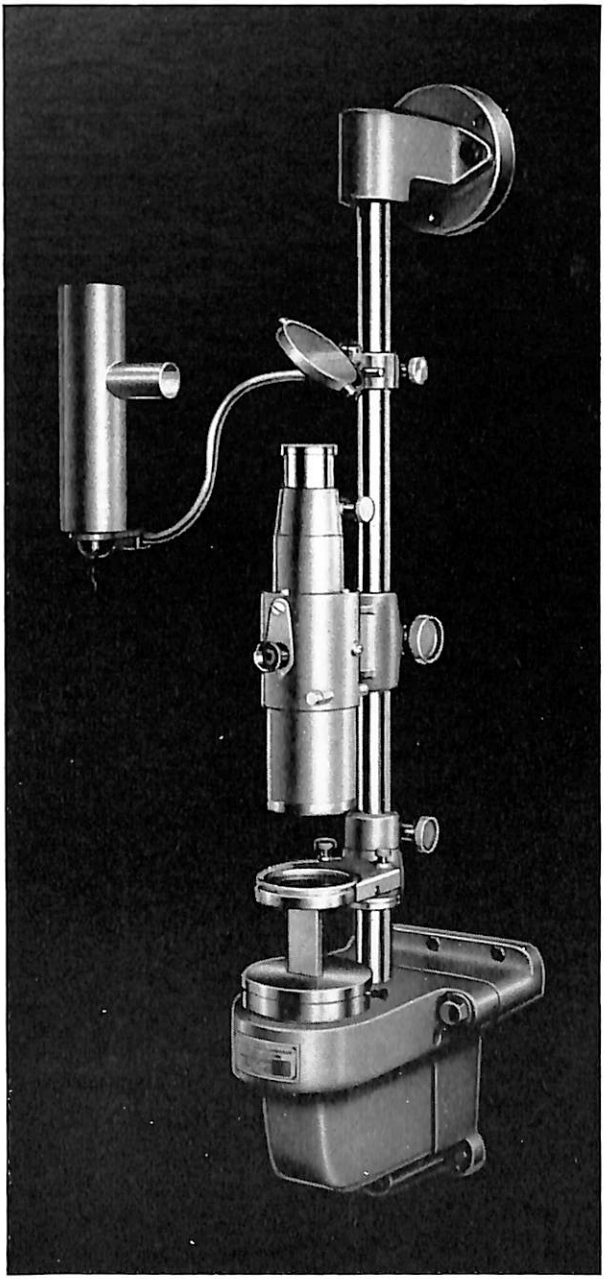
The Eden-Rolt "Millionth" Slip Gauge Comparator
(partly dismantled to show construction).

This is due to the fact that the various rays of light have different path lengths to travel between the optical flat and the reflecting surface. When the distance is such that the reflected ray is in phase with the incident ray, light is seen, but a short distance away—dependent upon the angle the flat makes with the reflecting surface—the reflected ray will be completely out of phase with the incident ray, and darkness will occur.

The result will be a more or less gradual change from brightness to darkness, and the actual effect is to show a narrow band of light and a narrow band of darkness, which, from a truly flat surface, recur at regular intervals.

Two instruments are available—one is carried on a bracket (which should be mounted on a wall free from vibration) and the other has been designed for use on a bench and is carried on a heavy base. Both instruments are identical apart from their method of mounting. The optical flat is mounted on a bracket which is adjustable on the vertical pillar of the instrument, and is also capable of being inclined by means of fine pitch screws. The optical flat can be swung clear of the platen to facilitate setting. A piece of fine wire stretched across the diameter of the optical flat provides a means of comparing the straightness of the fringes. Vertical adjustment is provided for the optical flat and lens brackets. The platen is rotatable in its own plane, and can be checked for flatness and parallelism on the machine itself.

It is well to appreciate from the start that only by care and patience can the best results be obtained from this highly sensitive instrument. When adjustments to the position of the optical flat are called for, it should be borne in mind that only a very slight turn of the adjusting screws may be required, and that by a movement of as little as a quarter turn on one screw the interference bands may completely disappear.



The "Matrix" Interferometer.

The following diagrams give an indication of what to look for and how to interpret the meaning of the interference bands on the work piece and platen.

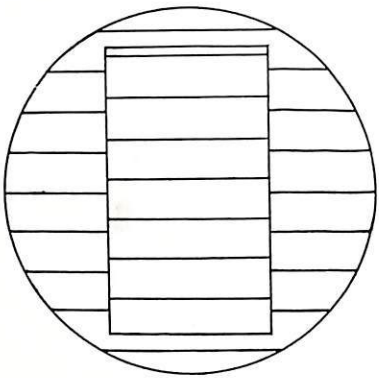


Fig. 3.

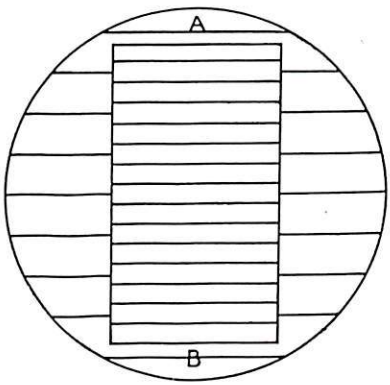


Fig. 4.

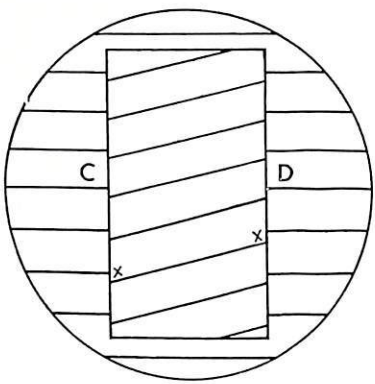


Fig. 5.

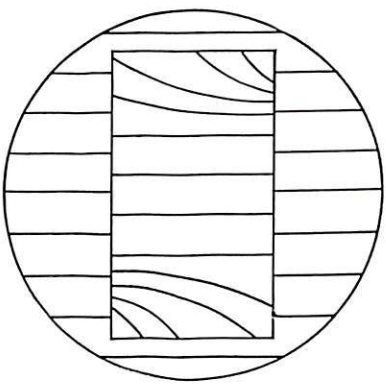


Fig. 6.

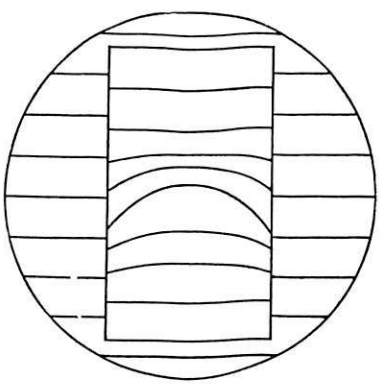


Fig. 7.

If the fringes on the work and platen appear straight and of the same pitch, although not necessarily in phase, the work can be assumed to be both flat and parallel in both directions. Fig. 3 gives an impression of the image.

Work which is flat but tapered from A to B will appear as Fig. 4. The fringes on the work though parallel and equally spaced, are greater in number than those on the platen, showing that there is an angular difference between the platen and the piece under test. To ascertain the actual amount of taper, the number of bands on the work piece are counted, and, without disturbing the setting of the machine, the platen is rotated through 180°. In this position the bands are again counted. Half the difference in the number of bands × ·00001″ will give the amount of taper present.

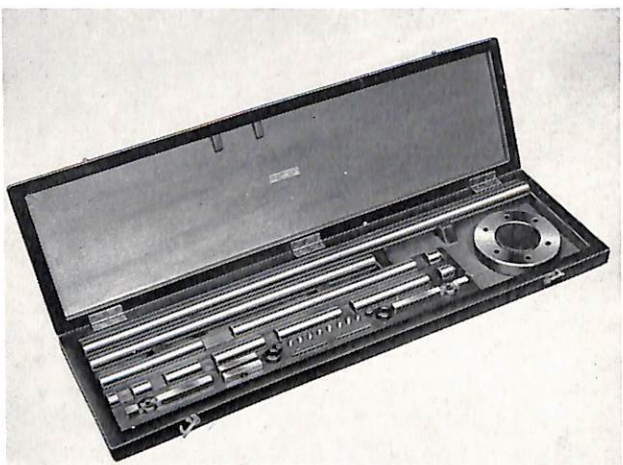
If the image appears as in Fig. 5, with the fringes on the work running out of parallel to the fringes on the platen, then taper is present between edges C and D. The actual error can be estimated by the amount that the bands on the work are out of parallel with those on the platen. In this case one fringe, giving a taper of ·00001″ over the width C.D.

Work which is flat in the centre with a tendency to round off at each end would appear as in Fig. 6. The flat and parallel area is indicated by the parallel fringes of the same width as those on the platen. The edges which are falling away produce curved uneven fringes.

A depression towards the centre of the work would be indicated by several straight fringes at the edges, gradually becoming curved towards the centre, as shown in Fig. 7.

The range of use of both length bars and slip gauges can be considerably increased by the use of the various sets of accessories. Special type jaws are made for use with end bars for workshop use that enable them to be used to make up gauges for either internal or external measurement, or, alternatively, they can be mounted on a special base and used as height gauges.

A set of "Matrix" Slip Gauges comprising 81 pieces.



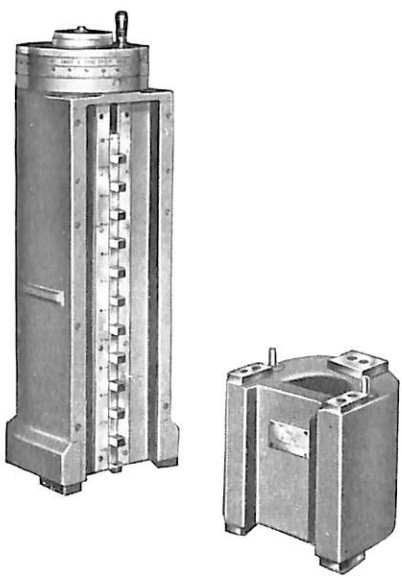
"Matrix"
Length Bar
Set complete.

"Matrix" Slip Gauge Accessories.

Cages of various lengths and special jaws enable slip gauges to be used for the same purpose without fear of the combination breaking, and they can also be used as height gauges in conjunction with the base. The special centre or scribing points used in conjunction with the cages and base enable precision marking to be carried out.

The "Matrix" Height Setting Micrometer is a development combining the accuracy of slip gauges with the speed of use of a micrometer.

Height settings to an accuracy of ·0001" are obtained over its complete range of 12 inches in a fraction of the time required to build up Slip Gauges. The range may be extended by the use of one or more 6" Risers.



"Matrix" Height Setting Micrometer.

The Millionth machine is, of course, not suitable for measuring cylindrical gauges, and one of the many types of comparator on the market would be selected for this, taking care to choose an instrument of a sensitivity suitable for the accuracy required.

Generally speaking, we can say that a comparator that can be read to one decimal place closer than the final accuracy required is desirable. Thus in a Standards room where it is required to know the sizes of gauges to ·00001″ we should use a comparator graduated in units of ·00001″, which could be used by estimation to the millionth.

In the Toolroom where we require the "tenth" with accuracy, we should select a comparator reading to ·0001″ direct and to ·00001″ by estimation, whilst for the more general run of production work we should use a comparator reading in thousandths of an inch with a consequently greater range of measurement.

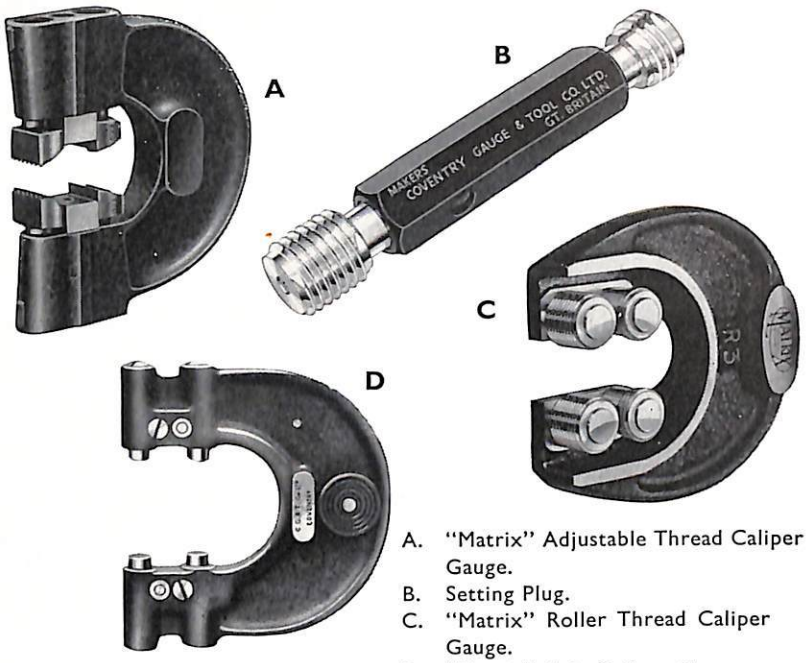
When producing plain cylindrical work to close limits it is desirable to use a suitable comparator and adopt some form of quality control, but where the tolerance is ·0005″ or more the "Matrix" Plain Adjustable Caliper Gauge will be found equally valuable for Shop or Inspection use.

The measurement of externally threaded components becomes a little more difficult, but for rapid inspection to close limits the "Matrix" Adjustable Thread Caliper Gauge is invaluable and is sensitive to feel to ·0001″. The gauge has a wide range of adjustment, permitting the use of the same gauge on a variety of components having the same pitch, and can be used for right- or left-hand threads. It is quickly set, and can be sealed and made tamper-proof. Another gauge that finds favour with many is the Roller Type Caliper, which can also be used for right- or left-hand threads, but its range of adjustment is limited. The rollers have a long life, and it is suitable for long production runs of the same size thread where there is a fairly wide limit.

One of the many types of Electrolimit Gauges developed by Messrs. Taylor, Taylor & Hobson Ltd., of Leicester.

It is possible to set both types of caliper with slip gauges, but it is recommended that a setting plug is used, as the caliper can be checked frequently without any more trouble than inserting a component.

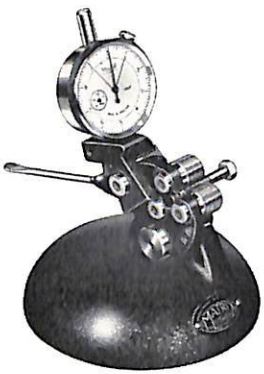
By sighting the component against the anvils of the "Matrix" Adjustable Thread Caliper and using an eye glass, the form of thread can be examined, an assessment can be made as to the accuracy of pitch of the component and any serious drunkenness of the thread will also be revealed.



A. "Matrix" Adjustable Thread Caliper Gauge.
B. Setting Plug.
C. "Matrix" Roller Thread Caliper Gauge.
D. "Matrix" Plain Caliper Gauge.

Where quality control is employed the "Matrix" Tri-Roll thread comparator should be used. Two Instruments can be employed side by side, one with "Full Form" rollers checking the virtual size of the thread, that is including errors in pitch angle and form, and the other using special rollers to engage on the effective diameter only.

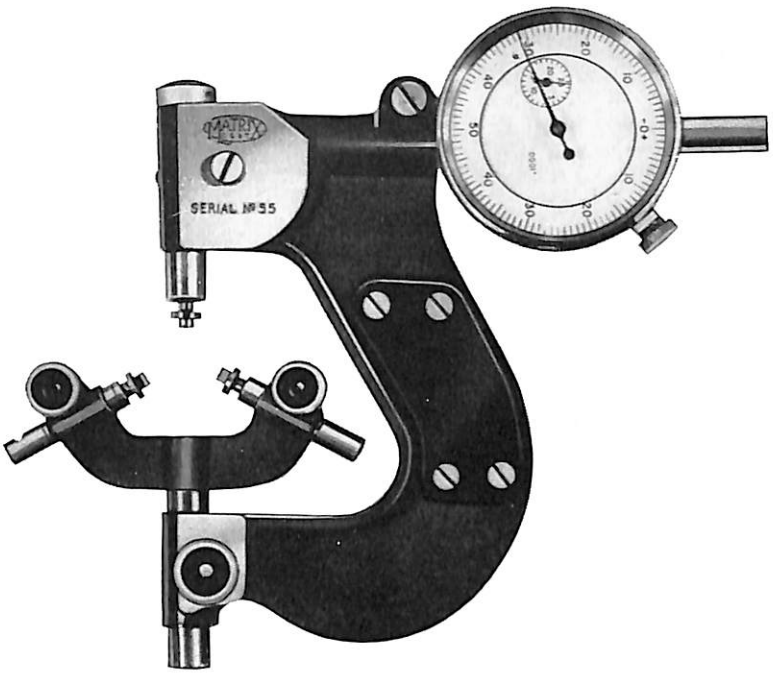
The Instrument is set with a calibrated setting plug and errors of the product read in units of ·0001" on the dial.



"Matrix" Tri-Roll Comparator.

A very accurate assessment of the quality of the product can be made together with predictions as to when tool setting or replacement will be required.

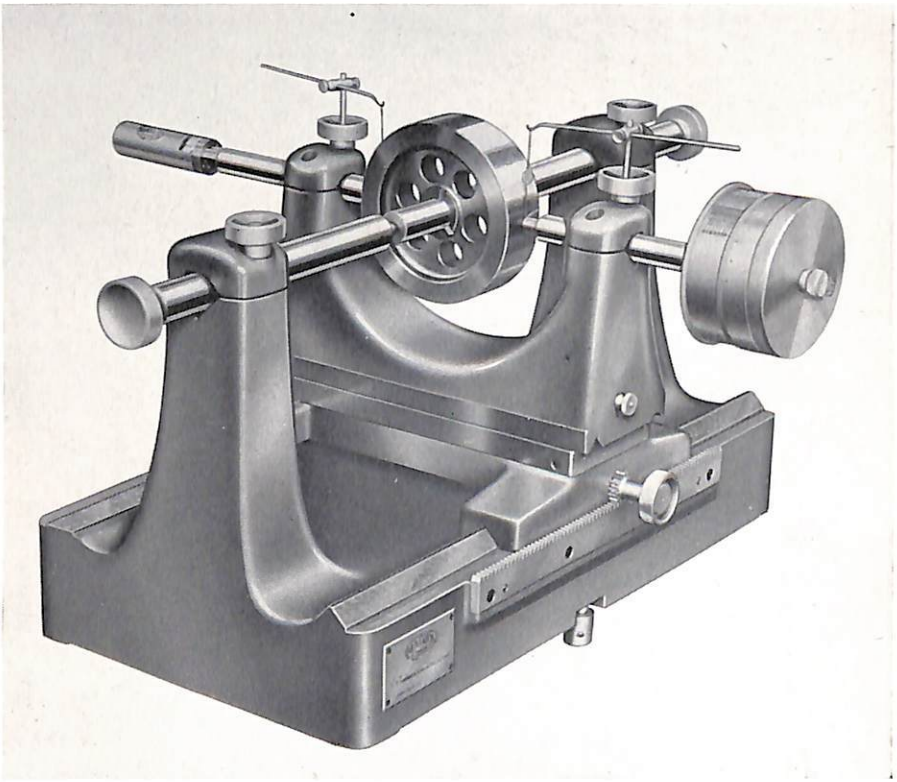
The comparators cover a range of diameters and the rollers, which are interchangeable for standard pitches, can be used for right- or left-hand threads.



The "Matrix" 3-Flute Tap Comparator.

A useful device that can be used both for production and quantity inspection is the Three-Flute Tap Comparator. This instrument can be obtained with a range of measuring anvils to cover the pitches required, and can be used to check three-flute taps ranging from No. 10 B.A. up to $1\frac{1}{4}$" B.S.W. The design permits the anvils to swivel and take up the correct helix angle of the thread, and may be used to check either right- or left-hand threads. The instrument is set by means of an ordinary screwed setting plug, and the size of the tap is read direct in units of ·0001" on the dial of the indicator.

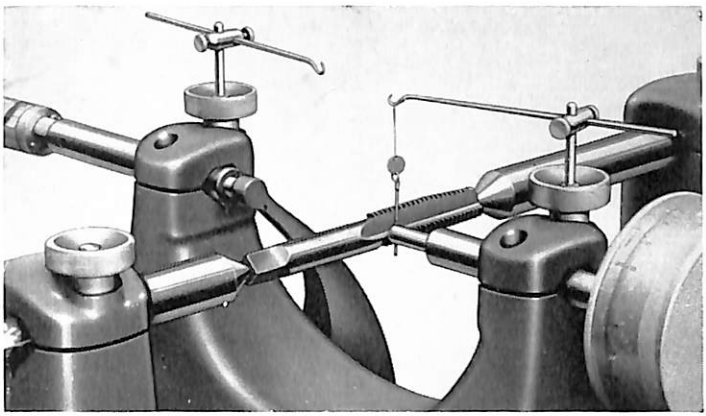
For the production of accurate Screw Plug Gauges the "Floating Carriage" Diameter Measuring Machine is essential. These machines are easy to use and have equal value both in the Toolroom and the Standards room. They are made in various sizes and cover a range of work from the smaller B.A. sizes up to gauges 12″ in diameter.



"Matrix" 0-7″ Floating Carriage Diameter Measuring Machine.

Most modern machines are fitted with micrometers that have been specially designed with anvils that do not rotate and are graduated to read direct to ·0001″. Opposite to the micrometer is a fiducial indicator that ensures a constant measuring pressure with consequent accuracy of measurement.

A simple device to enable the machines to be used for the measurement of odd fluted taps can also be supplied, and in addition to their prime purpose will be found useful on other work where radial measurements are required, including the measurement of the pitch circle radius of gears.



The Odd-Flute Tap Attachment on a
0-4" "Matrix" Floating Carriage Diameter Measuring Machine.

Measurements on the Effective or Pitch Diameter are carried out with the aid of small cylinders or measuring wires that make contact approximately half-way down the flanks of the threads, readings first being taken over a cylindrical standard of known size and then on the gauge. A simple calculation gives the size of the effective diameter, and the method is more accurate than that of setting the machine with slip gauges and calculating a reading over the cylinders. The core or minor diameter is obtained in a similar manner, using prisms instead of the cylinders.

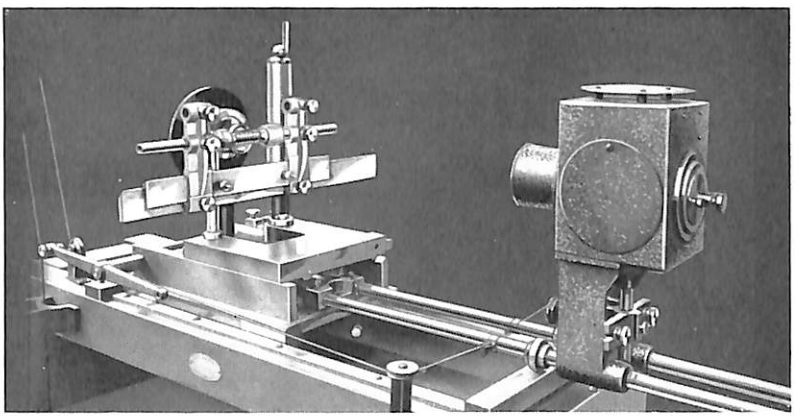
In order to obtain the greatest accuracy, it is desirable that the size of the Cylindrical Standard used shall be reasonably close to the size to be measured, and they are obtainable in a range of sizes that will be found to cover all requirements.

Cylindrical Standard.

Thread Measuring Cylinders and Prisms.

In order to ensure that screw threads are of the correct angle and profile they are projected on to a screen or viewed in a microscope. There are many types of projection apparatus available, all having their merits for particular classes of work, and the choice of a projector must be determined by the size and type of work it is desired to examine. The horizontal type originally designed by the National Physical Laboratory is a good general purpose instrument for small and medium size screws of moderate helix angle, the angle of thread being measured by means of a protractor, and the profile checked against a standard thread form diagram, the projected image representing an axial section of the screw.

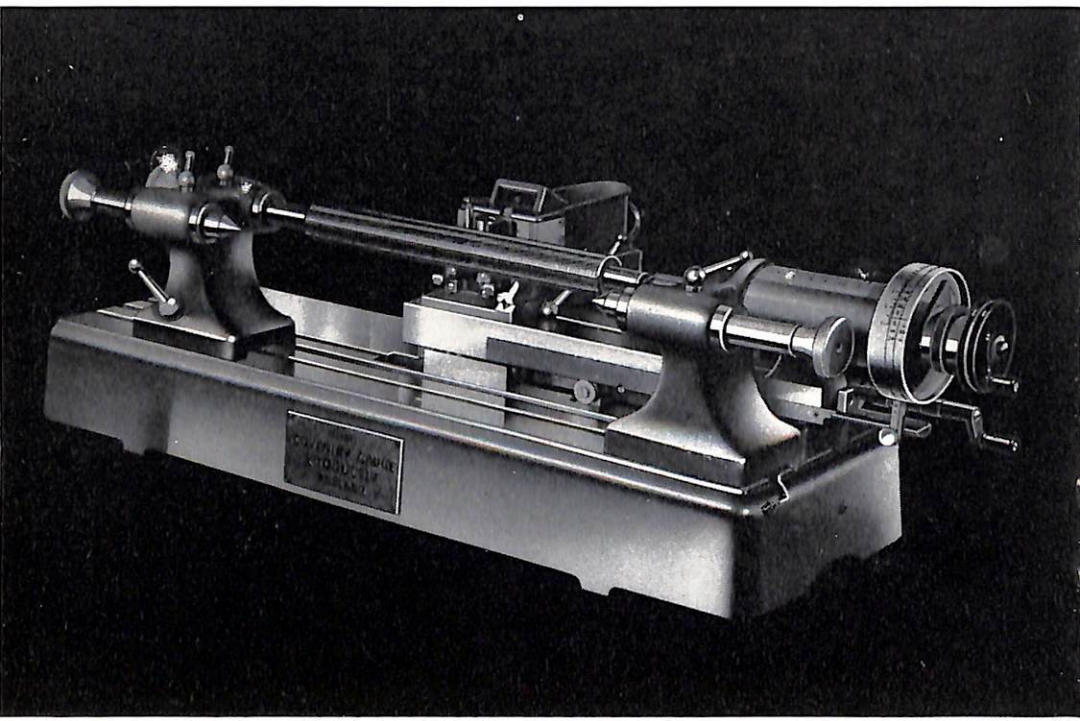
Non-standard thread forms and profile gauges may be checked against a layout drawn to the required magnification on Bristol board or cartridge paper. Owing to the tendency of these materials to contract or expand with variations in humidity, the maximum dimensions of the layout should be checked in both directions each time they are used so as to ensure that they are correct.



The N.P.L. Horizontal Projector.

Another very useful machine is the Toolmakers' Microscope which will accommodate screws with a helix angle up to about 7°, but in some cases the projection is normal to the helix which must be taken into account when making accurate measurements on threads of fairly coarse helix angles.

The Instruments can be obtained with a range of eyepieces containing graticules covering the range of standard threads, or a range of radii. Eyepieces can also be obtained with a series of crosslines and a protractor scale which enables measurements to be made on quite intricate form gauges. The majority of these instruments can be used either with a microscope eyepiece or a projection attachment with a range of magnifications up to 50X.



The "Matrix" Type T.S. Pitch Measuring Machine.

The pitch of a screw, particularly a gauge, must be rigidly controlled, any departure from nominal introducing a virtual error in diameter of a magnitude of approximately twice the error in pitch.

Pitch measurements are best made mechanically, and several years ago the National Physical Laboratory designed a machine for this purpose, on which both Plug and Ring gauges could be checked to an accuracy within ·0001″.

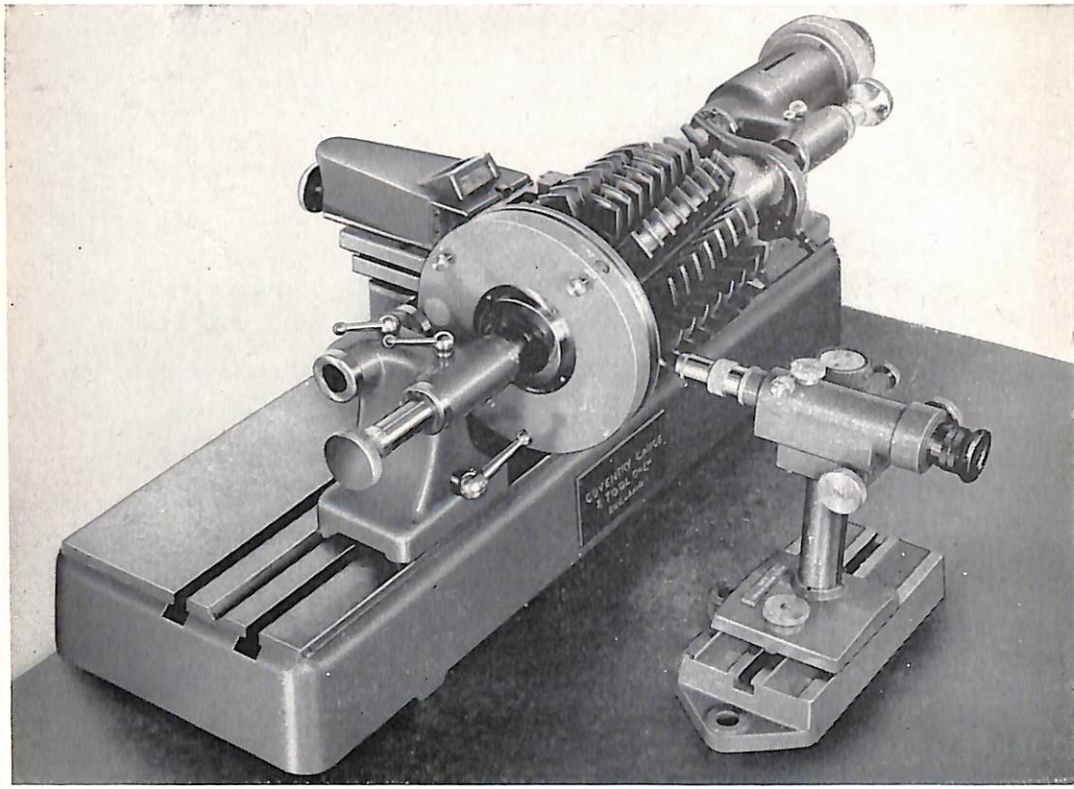
This type of machine still performs useful work on small and medium size gauges, but the demand for greater accuracy on work beyond the capacity of this machine led to the design of the "Matrix" Type T.S. Pitch Measuring Machine, which has a capacity of 18″ between centres and will check gauges up to 8″ in diameter.

The micrometer, which is of special design, has a 2″ run, and is fitted with a compensator bar to remove any residual pitch error present after assembly, and also provides adjustment for wear should this become necessary.

Another feature is the provision of a Sine Bar Attachment with a simple quick-set scale that enables measurement to be made in an axial direction along a taper screw up to an included taper of 1 in 4.

Both plugs and rings can be measured on this machine, and various attachments and stylos are provided which enable rings as small as No. 6 B.A. to be checked.

A simplified version of this machine without the sine bar attachment is available if parallel screw threads only are required to be measured.



Checking a Hob on the "Matrix" Type T.S. Pitch Measuring Machine.

The accurate measurement, particularly the Angle and Form, of Large Hobs such as are used for cutting turbine gears has always presented a problem, but by a combination of instruments we are now able to do this quite efficiently, although a thorough inspection takes some considerable time.

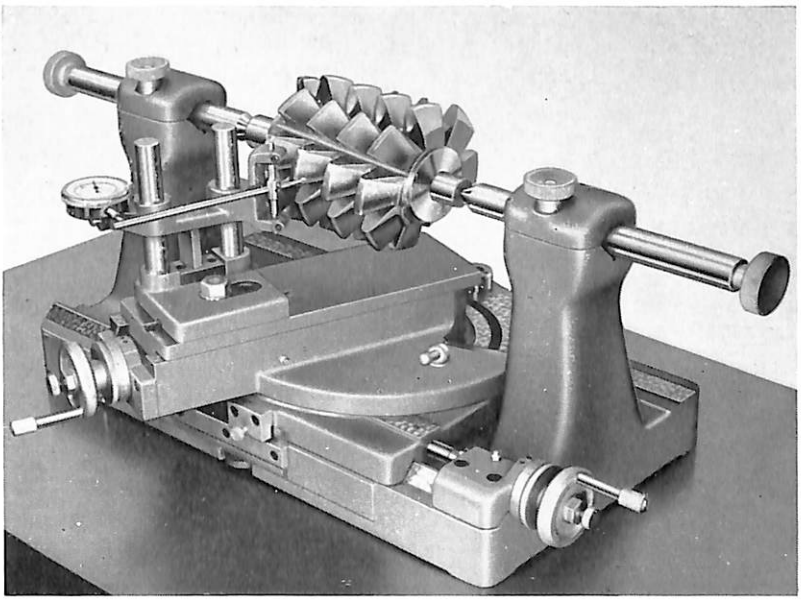
Pitch measurements on a straight fluted hob can be quickly carried out on a "Matrix" Pitch Measuring Machine, but if the hob is spiral fluted it is desirable to make use of the Watts division tester set-up as shown above.

Having made this set-up, not only can we check the axial pitch, but if the hob is multi-start, the spacing of the starts can also be checked. By taking additional readings,

"drunkenness" or lack of progression from a true spiral can be measured By fixing a small dial indicator to the machine the spacing of the flutes can be checked, also the spiral lead of the flute. Any offset from centre of cutting angle over the depth of tooth can also be determined.

The large deep teeth on this type of hob are extremely difficult to project, and a machine has been designed to check the tooth form mechanically, and is known as the "Flank Angle Measuring Machine".

The machine has been designed to check Hobs, Worms, Involute Helicoids, etc., on the principle that all helical surfaces are generated by a straight line.



The "Matrix" Hob Flank Angle Measuring Machine.

The deviations from a straight line are registered on a stylus-actuated indicator with one division of the dial being equal to ·0001″ movement of the stylus.

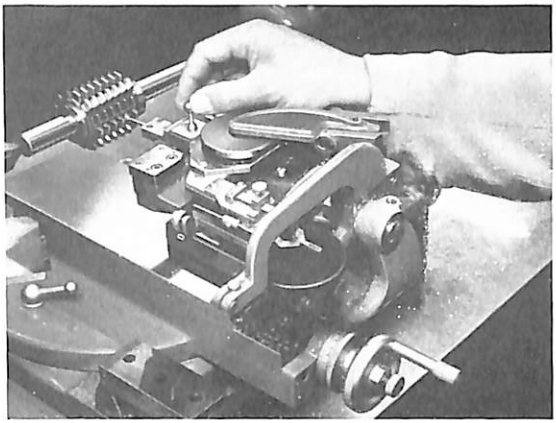
For the inspection of a Hob or Worm straight sided in a plane normal to the axis, the indicator is set by means of slip gauges, so as to be on the centre line.

The indicator is mounted on a cross slide, which in turn is mounted on a swivelling table, which can be set by means of slip gauges on the Sine Bar principle, to the angle required. Traversing the top carriage with the stylus engaged on the flank of the hob or worm shows any departure from the nominal angle direct in units of ·0001″.

In the case of a hob or worm of involute form the stylus must be raised or lowered from the line of centres, according to the hand of the helix, by an amount equal to the base-circle radius, and the swivelling table set to the base lead angle.

The Indicator of the Flank Angle Measuring Machine can be replaced by the "Matrix" Profile Recording Instrument which enables the profile of the tooth to be traced on a smoked glass plate in a plane normal to the helix or axis as required. The tracing is at unity magnification and can be projected or examined on a toolmakers' microscope at any desired magnification.

The Profile Recording Instrument can also be used on a base, on a surface table or the bed of a machine and has many uses for checking forms that cannot be projected such as internal ogival forms and in some cases profile features of built-up position gauges. The Instrument is designed to cover an area of 1 inch square.



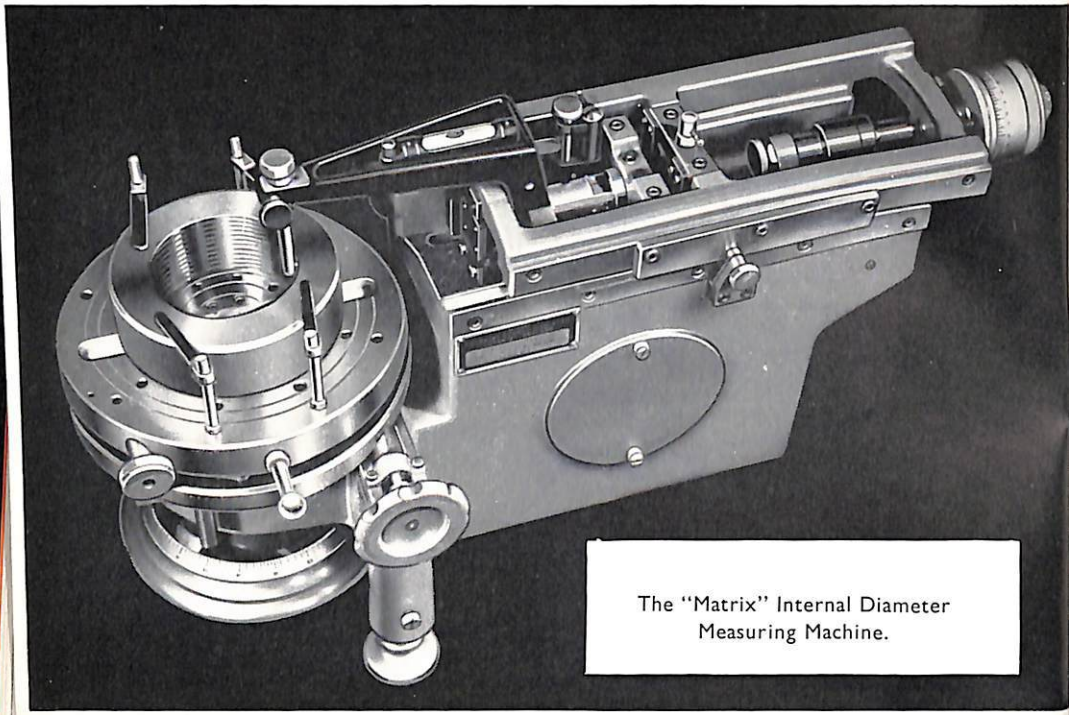
Profile Recording Instrument.

A machine for the accurate measurement of Internal Diameters has been developed by this company, and has a capacity from $\frac{1}{4}$″ to about 6″ diameter over a depth of 2″.

Although designed primarily for the measurement of internal threaded work, the machine is fully universal, being capable of measuring accurately work that is plain or threaded and parallel or tapered, and by means of a small biasing lever, external measurements can also be made if desired. At the same time as diametral measurements are being made, readings of the vertical micrometer, essential for taper measurements, can be taken and any errors in pitch ascertained.

The work table can be rotated accurately through 180° by means of stops, and also traversed in a crosswise direction. It is mounted on a massive 10 T.P.I. screw, and can be moved vertically over a range of 2″. The screw is accurately made, and the provision of a graduated elevating wheel enables this movement to be accurately ascertained to ·0001″.

The top carriage runs on balls on hardened and lapped ways. A micrometer having a 1″ travel is attached to the carriage and is used in conjunction with a Fiducial Indicator, ensuring a constant measuring pressure of approximately 8 ozs. There is a fixed abutment, to which end bars of



The "Matrix" Internal Diameter Measuring Machine.

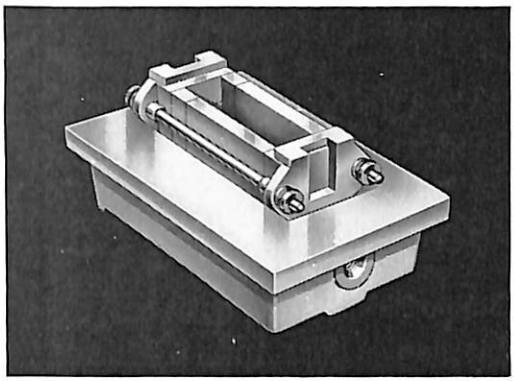
various lengths can be attached to accommodate different diameters of work, and the top carriage is biased by means of a small weight in the direction of the abutment, to ensure positive contact of the micrometer anvil and end bars.

A ball-ended stylus is used for the measurement of plain work, and special stylos having radii suitable for the various pitches are used on threaded work.

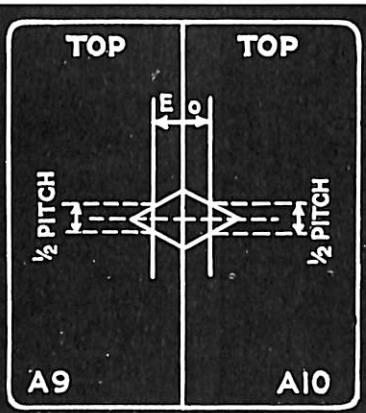
The machine is set by means of a composite standard consisting of plain or grooved end pieces, depending on the type of work to be measured, separated by slip gauges so as to produce a standard about the same size as the work, the whole being mounted in a cage as a unit.

In the case of plain work, the size is, of course, that

of the slip gauges, but when the grooved pieces are used, a constant, applicable to the pitch to be measured, is added to the size of the slip gauges.



The Composite Standard.



BLOCKS A9 and A10

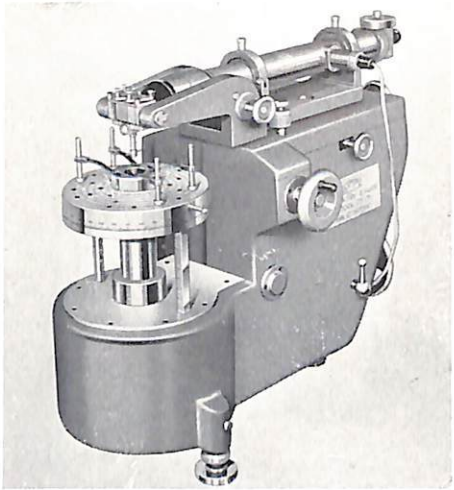
T. P. I. Whitworth	"Eo" Value at 68°F Inch
10	0·0151
11	0·0236
12	0·0311
14	0·0426

The National Physical Laboratory has recently developed a machine for the measurement of plain parallel bores over a range of 0·01″ to 3·0″ to an accuracy of at least 0·00001″.

Measurements are made in comparison with a box

standard built with slip gauges and the indicating mechanism consists of small adjustable mirrors attached to the unit carrying the measuring stylus.

Light reflected from these mirrors is viewed in turn in an autocollimator which is graduated in 0·2 second divisions, the length of the measuring stylus being such that 0·1 second of arc is equal to 0·000001″.



N.P.L./"Matrix"
Internal Measuring Machine.

Production Internal Screw Threads are, of course, normally checked by means of a Full Form 'Go' Screw Plug Gauge and a 'Not Go' Effective Diameter Gauge, which is truncated on the major diameter and cleared at the minor diameter to ensure that it bears only on the effective diameter. A plain 'Go' and 'Not Go' Gauge is used to ensure that the minor diameter of the component is within limits.

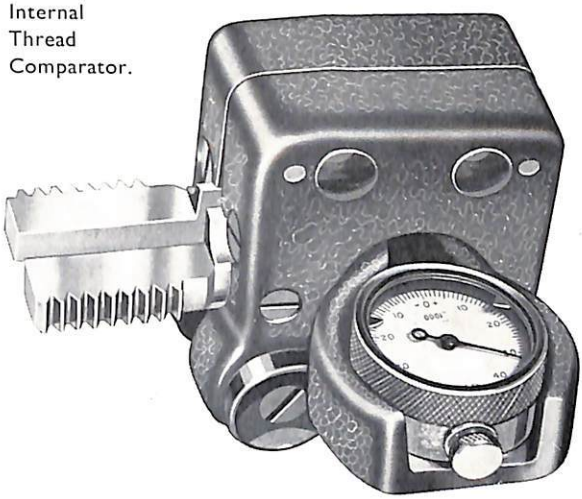
A useful instrument for the quality control of internal threads is the "Matrix" Internal Thread Comparator.

It consists of a small light frame carrying an indicator and a pair of anvils applicable to the thread to be measured. The comparator is set to a calibrated screw ring and the size of the component read directly in units of 0·0001″.

The anvils are interchangeable and are made for all standard threads between $\frac{1}{4}$″ and 1″ diameter.

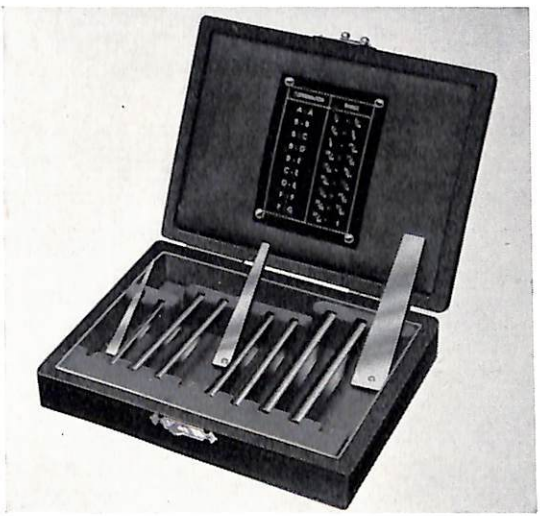
When only a small number of large components are required to be internally threaded, measurement by an internal micrometer with special ball-ended anvils can be adopted.

"Matrix" Internal Thread Comparator.



Plain internal components may be gauged with a simple 'Go' and 'Not Go' plug gauge or one of the several forms of expanding gauge or internal dial gauge available.

A simple form of the expanding gauge is the "Taper Parallel", which can be obtained in sets hardened and ground to close limits. Such a set as illustrated enables holes of any size from $\frac{1}{4}$" to 1" in diameter to be quickly checked with the aid of an ordinary hand micrometer.



Set of Taper Parallels.

An instrument that has made the accurate measurement of plain holes really easy is the "Matrix" Micro-Maag Internal Micrometer.

These can be obtained in a range of sets to cover all sizes from $\frac{1}{4}$" in diameter up to 8" diameter, and by the use of extension pieces, deep or long holes can be measured without any loss of accuracy or sensitivity of feel. As an example, using the set covering the range 1·0" to 2·0", bores can be measured to a depth of 15" to an accuracy of ·0001".

The Measuring Heads incorporate radially arranged measuring anvils, which are spread by the displacement of a tapered needle until they contact the wall of the bore to be measured. The axial displacement of the needle corresponds to the size of the bore, and can be read on the micrometer drum. The tapered needle transmits the motion of the micrometer screw to the axial travel of the measuring anvils at the rate of the taper. Any error in the micrometer screw, or the extension pieces if they are used, is thus reduced at the same ratio.

The anvils are held against the bore by spring pressure and the feel on the micrometer is positive. There is no connection between the micrometer and the anvils until it is screwed down to make contact when it comes to a positive stop, and repetition of reading to ·00005" can easily be obtained.

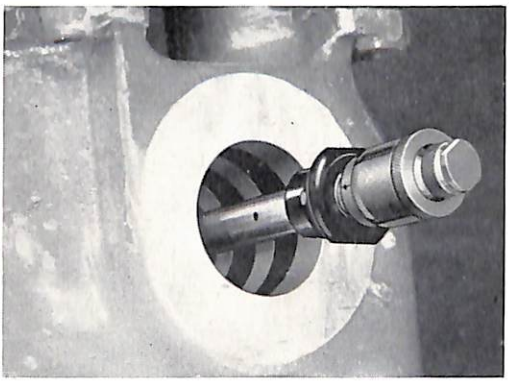
The production of plain taper work is usually carried out by means of taper gauges, the machine being adjusted until the component is a good fit to the ring or plug, as the case may be, and within the limit steps provided.

The measurement of the Ring gauge, both for rate of taper and size, can easily be carried out on the "Matrix" Internal Diameter Measuring Machine if the length does not exceed 2". If of greater length, or a measuring machine is not available, measurement can be carried out by using accurate steel balls of various sizes. The amount the different balls sink below the large end face of the taper

THE "MATRIX" MICRO-MAAG INTERNAL MICROMETER.

Set EBO5 which covers a range from ½" to 1".

The assembled Unit.



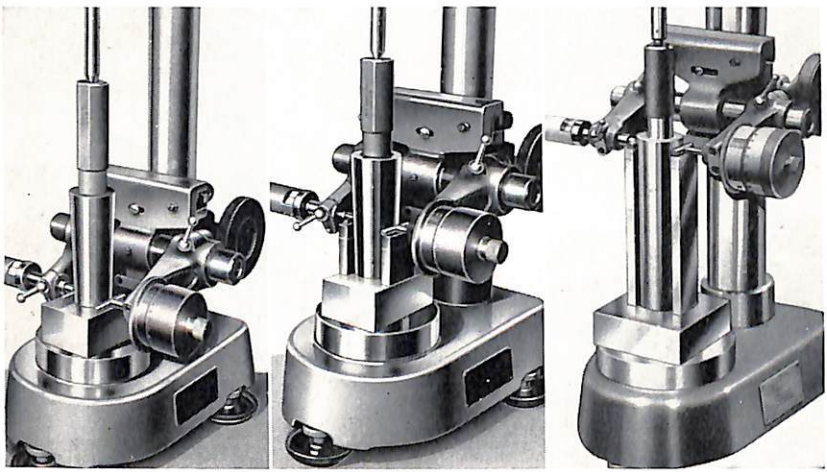
Measuring a series of annular lands of equal diameter with the "Matrix" Micro-Maag Internal Micrometer.

Plain Taper Plug & Ring Gauges.

enables the size at the large or small end of the ring, together with the rate of taper, to be calculated.

The measurement of a taper plug gauge can be carried out more easily and to a greater degree of accuracy by means of a pair of accurate cylinders and slip gauges, especially if a "Matrix" Taper Measuring Machine is available.

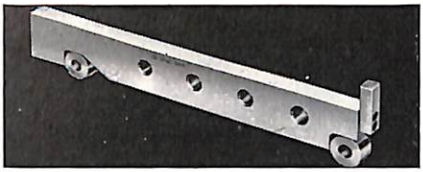
This machine employs a Micrometer Head with an enlarged drum reading direct to ·0001″ and a non-rotating anvil, which, in conjunction with a Fiducial Indicator,



Measurement of a Plain Taper Plug Gauge.

ensuring a constant measuring pressure of about 8 ozs., is mounted on a bracket that "floats" in the horizontal plane. The bracket can be raised or lowered on the pillar to enable measurements to be made at any desired height within the capacity of the machine, the size and rate of taper being quickly determined from the diameter/height readings obtained.

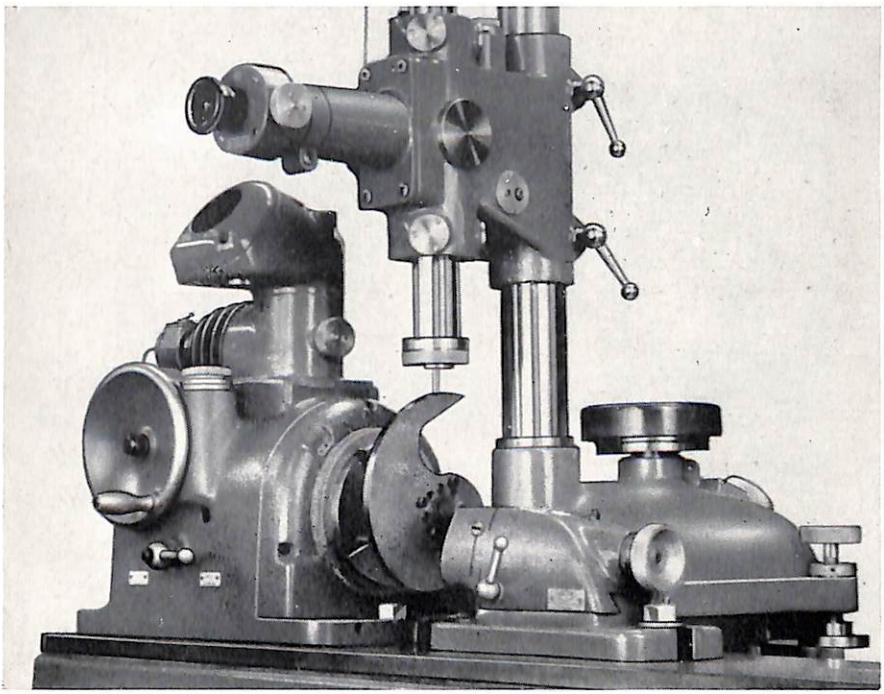
There are a number of ways of carrying out angular measurement, a lot depending on the type of work to be measured and the degree of accuracy required.



For some of the simpler work the 5″ or 10″ Sine Bar is eminently suitable, and its use can be extended by the addition of a precision angle plate or cube.

Whilst this method is suitable for a large variety of plate and position gauge work, a dividing head becomes essential when we consider the manufacture and checking of spline and serration gauges and cams of various types.

An Optical Dividing Head has been developed by Hilger & Watts Ltd. (Watts Division) and Coventry Gauge & Tool Co. Ltd., which can be read to 3 seconds of arc.

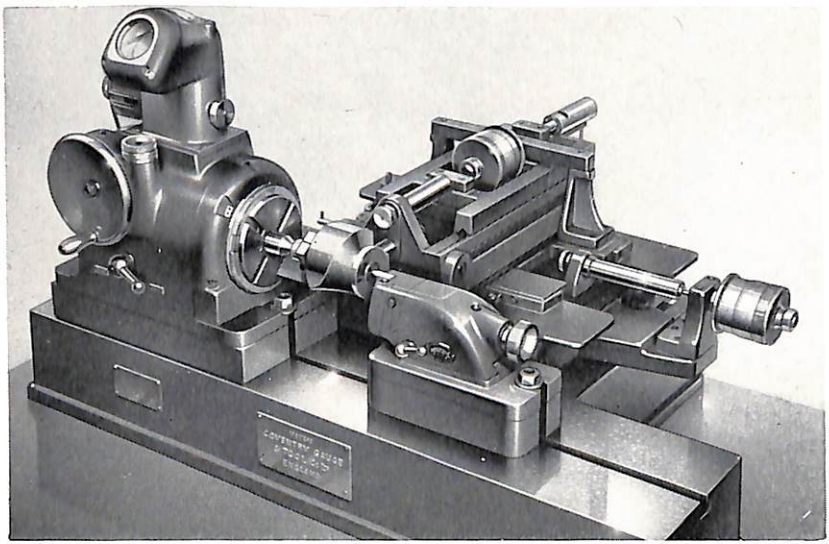


The Head used in conjunction with a Watts Microptic Measuring Instrument for checking cams to a high degree of accuracy.

(This means ·000015″ on a 1″ radius). It has a specially designed optical system which throws an image on to a ground glass screen, eliminating parallax and enabling two or more persons to view the readings simultaneously.

The picture (page 37) shows the dividing head set up for checking a cam, the rise or fall of the cam for a specified angular movement being read on the scale of the Watts Microptic Measuring Machine. This instrument is capable of being used for measurement over a range of 4″ to an accuracy of ·00001″, the readings being taken from a glass scale contained in the instrument body.

Not all cams are as simple as this, and it has been found necessary to design a machine known as the Three-Dimensional Measuring Machine to deal with cams of a more complex form.



The "Matrix" Three-Dimensional Measuring Machine.

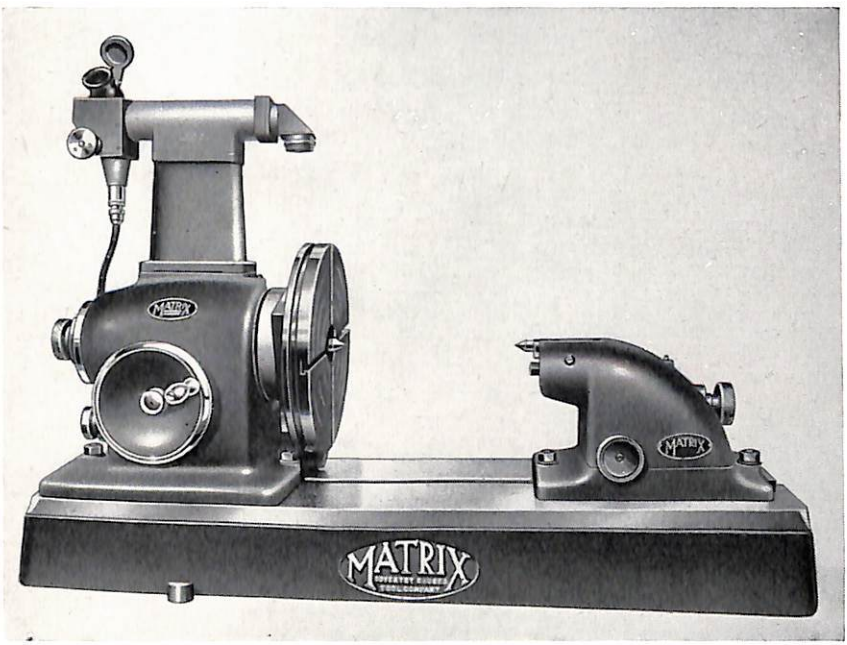
The main points of the machine are the optical dividing head, which gives us angular displacement; and the carriages, which slide in a radial and axial direction respectively. Provision is made for the use of end bars to extend the range of the micrometers, and a fiducial

indicator is incorporated in the carriage controlling radial measurement, to ensure a constant measuring pressure. The capacity of the machine is 12″ between centres and 8″ diameter, and measurements can be made along an axial length of 7″.

Certain classes of work require an extremely accurate method of division, particularly where large diameters are concerned, as it must be remembered that on a 5″ radius one minute means approximately ·0015″ round the circumference.

A special instrument known as the Angle Gauge Dividing Head has been developed in collaboration with the National Physical Laboratory, and is used with Angle Gauges designed by the late Dr. Tomlinson at the National Physical Laboratory.

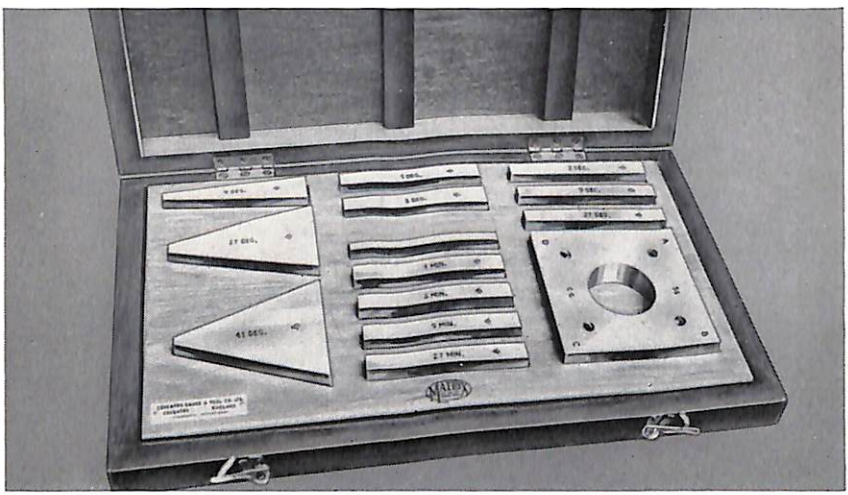
These Angle Gauges are made of hardened steel, specially seasoned and lapped to the same degree of



The "Matrix" Angle Gauge Dividing Head complete with Base and Tailstock.

accuracy of the standard parallel slip gauges, and although there are only twelve pieces, when used in conjunction with a square block made to the same degree of accuracy, any angle between 0° and 360° can be obtained in steps of 6 seconds of arc. This is achieved by wringing the blocks together in either a positive or a negative sense. For example, there are three gauges for fractions of a minute, ·1, ·3 and ·5 minute; and with these we can obtain also ·3 — ·1 = ·2 ; ·3 + ·1 = ·4 ; ·5 + ·1 = ·6 ; ·5 + ·3 — ·1 = ·7; ·5 + ·3 = ·8; and ·5 + ·3 + ·1 = ·9.

The other gauges in the set are 1, 3, 9 and 27 minutes and 1, 3, 9, 27 and 41 degrees, together with the precision square block, and it will be seen that with comparatively few gauges any combination can be quickly built up.



Set of "Matrix" Angle Gauges.

We return to the Dividing Head itself, the construction of which is extremely simple, but must be very accurately made.

The faceplate, which is driven by a worm and slow motion device, has a precision square block secured to its back face in such a manner that it can be moved without rotating the faceplate, or it can be locked to the faceplate

and so rotated with it. Mounted on top, with its telescope over the square block, is an autocollimator, which has a pair of crosslines in the eyepiece. These are controlled by a micrometer graduated in seconds of arc having a range of ± 15 seconds.

A beam of light from a self-contained lamp passes through the optical system, carrying with it the shadow of a fine line which is projected on to a face of the square. If the face of the square is normal to the autocollimator, a condition obtained in setting up, the light reflected from the face travels back along its outward path, and the image of the line is located between the crosslines in the eyepiece.

If the faceplate, with the square locked, is now given a very small rotation, the beam of light will hit the square at a small angle and be reflected back at an equal and opposite angle, and we see in the eyepiece the image displaced with regard to the crosslines. The crosslines can now be traversed by means of the micrometer until coincident with the image and the angle of displacement read from the drum.

It will be seen that, having made an initial setting on the square, angle gauges can be wrung on to any face of the square and the plate rotated until the face of the angle gauge becomes normal to the autocollimator, as indicated by coincidence of image and crosslines for zero micrometer reading. If the angle required cannot be obtained exactly by the Angle Gauges the crosslines can be offset by the appropriate number of seconds and rotation of the plate continued until coincidence is obtained.

Similarly, if a job is being checked for angular displacements of, say, 30° intervals, gauges totalling 30° can be used, the work being indexed round and any departure from the nominal angle of 30° read on the micrometer drum, providing it is within the range of ± 15 seconds.

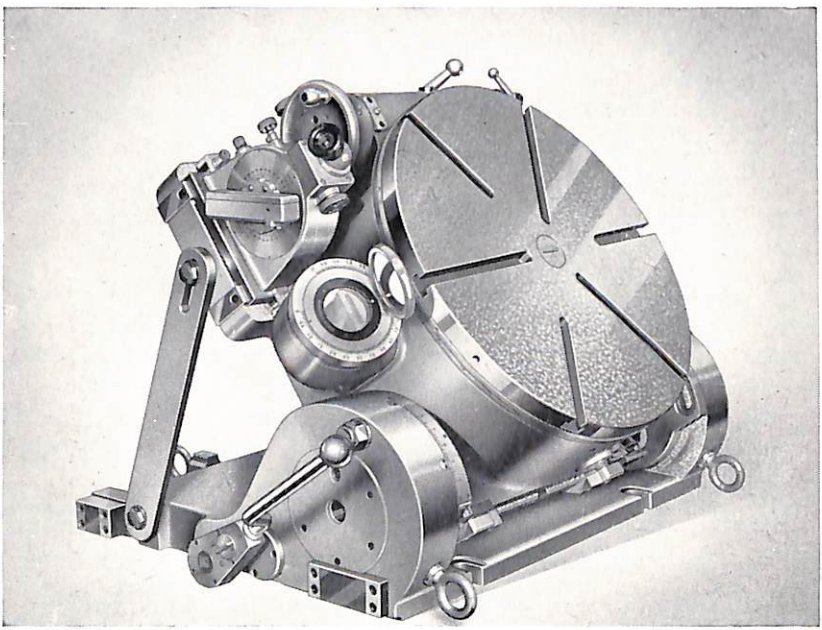
The extreme sensitivity of the instrument requires that something more sensitive than the usual ·0001″ dial gauge

is used for indexing if the highest degree of accuracy is required, as one second is equal to only ·000025″ on a radius of 5″ and correspondingly less for similar sizes.

A satisfactory method is to use a small sensitive level with ball feet or, alternatively, a high magnification Electronic Indicator may be used.

A very useful instrument both in the Inspection Department and the Shop, particularly on the Jig Boring machines, is the "Matrix" Optical Circular Dividing Table.

The table movements are projected on to a 3″ ground glass screen, which is protected from damage by armour plate glass, and by means of an optical micrometer, displacements can be read direct to 3 seconds of arc. The projection system is a completely sealed unit, impervious to dust and oil, and the illumination is supplied from an external lamp to avoid the effects of temperature, the light entering the system through a window of heat-resisting glass.

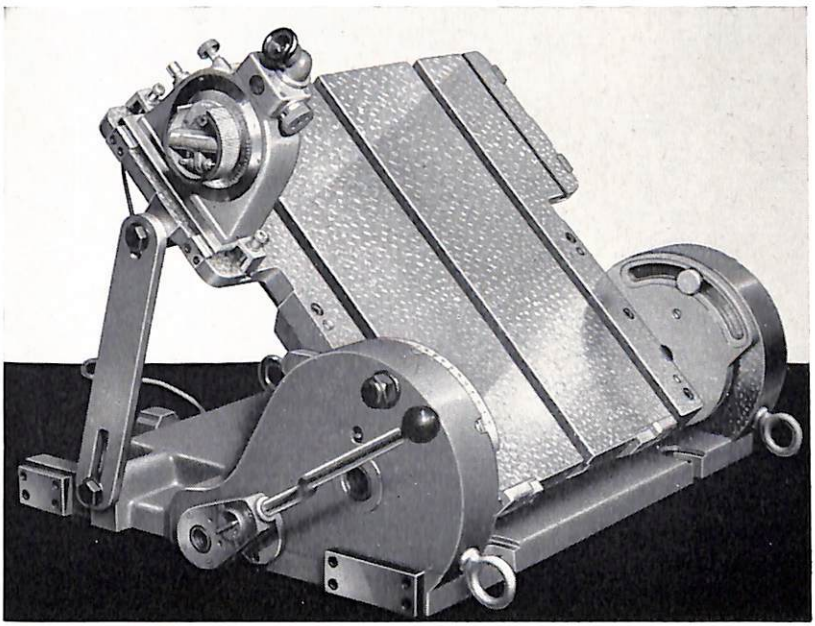


The 18″ Optical Circular Table mounted on a "Matrix" Inclinable Table.

The 18″ diameter table is finished flat and parallel to the base to ·0001″, and is provided with tee slots. It is rotated by an endless worm drive, spring loaded to eliminate backlash, which can be disengaged by a cam to permit free rotation if required. An external metal scale graduated at 30 minute intervals provides quick pre-setting, and the complete assembly is only 7″ high, so as to not unduly restrict the vertical range of use when on a machine.

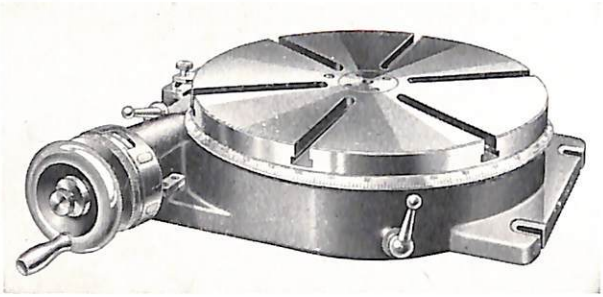
Designed either for use by itself or in conjunction with the "Matrix" Circular Table is the "Matrix" High-Precision Inclinable Table, the height of which, in its zero position, is only 4½″.

The top surface of the table is 26″ × 21½″, and is provided with tee slots and carries a platform on either side to permit the use of a Watts Microptic Clinometer for accurate setting of any angle up to 90° in increments of 10 seconds. Alternatively, Angle Gauges may be used in conjunction with a sensitive level. Pre-settings are made to a scale built into the left-hand trunnion of the table, and

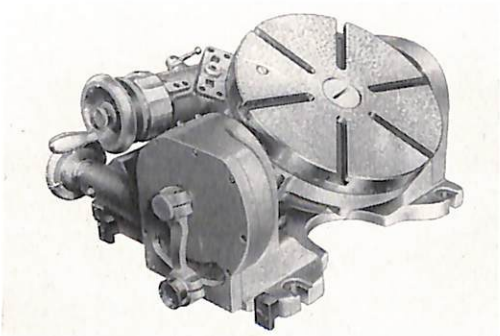


The "Matrix" Inclinable Table.

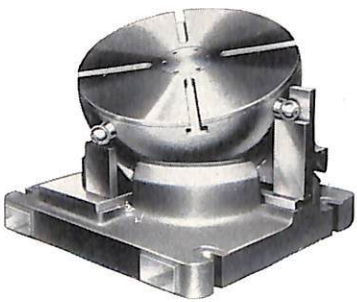
elevation is performed by means of a ratchet lever, and is smooth and positive. By means of gears and worm wheels the lifting pressure is equally distributed at each side of the table, ensuring accuracy of angle under the heaviest of loads.



12″
Circular
Table.



8″
Inclinable
Circular Table.



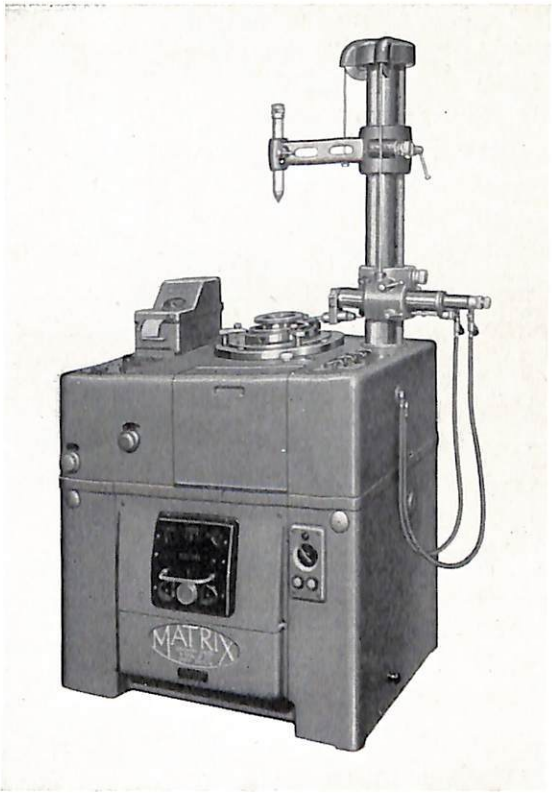
Compound Angle
Sine Table.

In addition to the Optical table, a number of mechanical tables have been designed to cover all the requirements for inspection, jig boring, grinding and light milling operations.

The "Matrix" 12″ Circular Table reads direct to 1 minute of arc and to 5 seconds by means of a vernier, with an overall accuracy of ± 10 seconds.

A Rotary table 8″ in diameter reading to the same degree of accuracy can be inclined at any position up to 90° to an accuracy of 1 minute of arc.

Of outstanding design is the "Matrix" Compound table which permits inclinations up to 45° to be made simultaneously in two planes to an accuracy of 10 seconds of arc. The table can of course be used for a single angle when required. The table is designed in the form of a hemisphere riding in a spherical seating, with two ball locations at 90° acting as 5″ sine arms, the settings being made with slip gauges.



Automatic Gear Teeth Spacing &
Concentricity Checking Machine.

The measurement of spacing normally carried out with a dividing head and indicator can be a lengthy process if there are many spaces to be checked, always with the possibility of setting errors due to fatigue, errors unfortunately that are not easily detectable when analysing results.

The "Matrix" Automatic Gear Teeth Spacing & Concentricity Checking Machine is the answer to the present day need for accurate and rapid checking of the spacing of gears, and also of spline and serration gauges—Index Plates, etc.

The machine has been designed as the result of several years' development work by the Mechanical Engineering Research Laboratory and after the machine has been set for the required spacing, automatically indexes and records on a chart the errors of each space in turn. Spacing is checked on each flank independently, and concentricity errors determined from a separate set of readings taken with the stylus engaging both flanks and positioned so that the indicator records radial movement.

Any gear having from 6 teeth upwards to a maximum diameter of 12″ can be measured, and gears up to a maximum length of shaft of 24″ can be accommodated between centres.

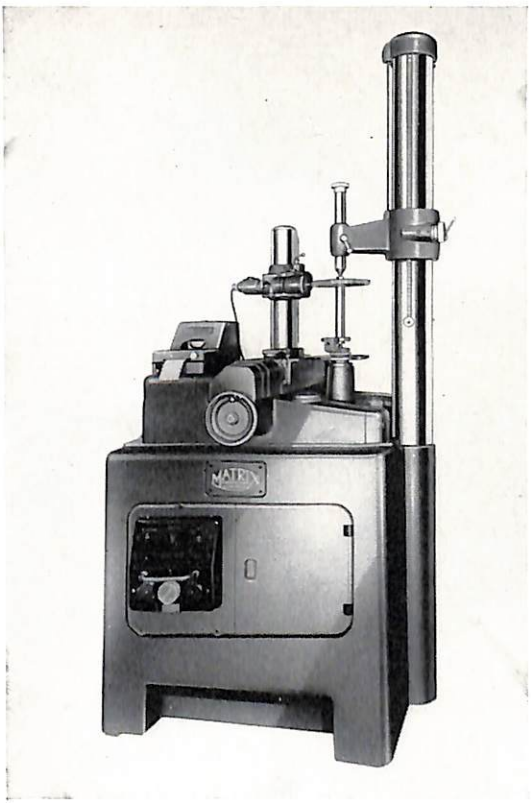
When all teeth have been checked the machine automatically ceases operation and displays a signal that it has ceased to operate.

The cycle time of operation is variable and is dependent upon the distance the machine is required to index. A cycle time of 12 seconds will suffice for a fine pitch gear, but 20 seconds is required for larger spacings. Taken at 15 seconds a gear having 120 teeth would be checked on flank or for eccentricity in only 30 minutes, with the result recorded and no attention during operation.

As a further aid to the production of high class gears a companion machine has been designed and developed for the checking of the Involute form.

Of similar capacity to the Automatic Machine the "Matrix" Involute Gear Form Measuring Machine employs the basic principle of generation, using a straight edge operating against a base circle disc.

The machine is fitted with a recording apparatus and a true involute will show as a straight line; any departure being clearly shown as plus or minus metal.



Involute Gear Form Measuring Machine.

The machine has been so designed that a Lowne sensitive indicator can be fitted if desired instead of the recording unit.

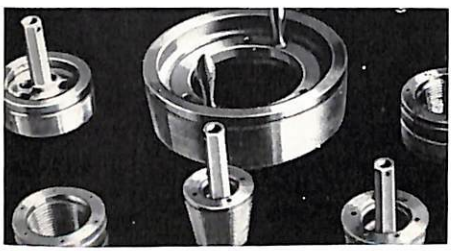
Certain of the classes of measurement described can be carried out with other types of instruments or by alternative methods. The fact that such alternatives have not been considered in the text is due to our desire to keep this book as brief and simple as possible.

Several of the Instruments described are made to the design of the National Physical Laboratory or made with their close co-operation.

OTHER

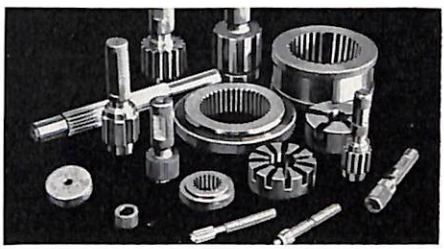
MATRIX

GAUGES, MEASURING INSTRUMENTS AND EQUIPMENT



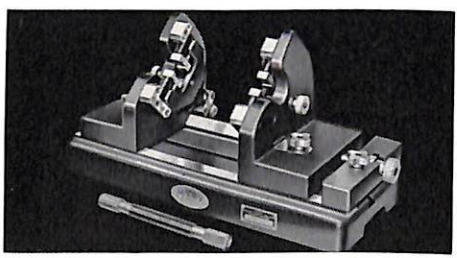
Taper Thread Gauges

Conforming to British Standard Pipe, American Petroleum Institute or American National Pipe Specifications.



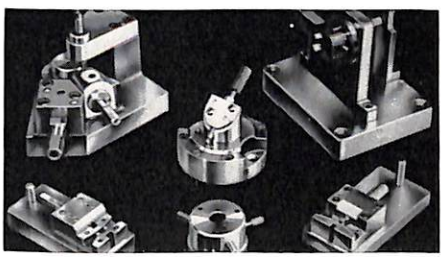
Spline and Serration Plug and Ring Gauges

To B.S.I. Specification or to suit customers' special requirements.



Pitch Continuity Checking Gauge

For checking the pitch of thread components of extended length such as Boiler Stay Bolts, etc. Simple to use yet gives extremely accurate results.

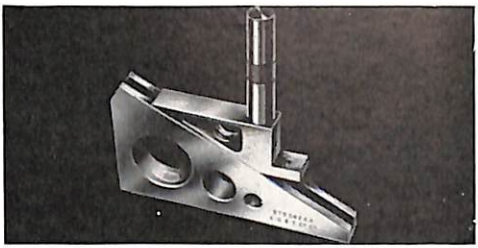


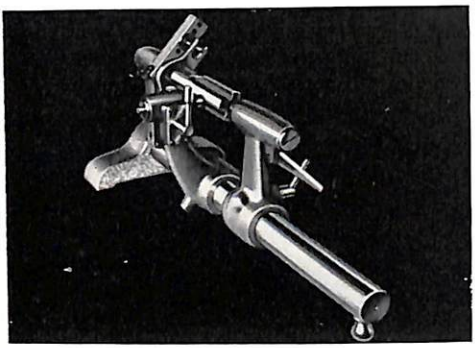
Receiver Gauges

The gauging of the most intricate components for interchangeability can be reduced to the simplest of operations by the use of correctly designed and accurately made Receiver Gauges. Gauges designed from drawings or actual components.

Planer and Shaper Gauges

Giving a range of tool settings quickly and easily from $\frac{1}{4}$in. to $8\frac{1}{2}$in. Made from high grade steel, hardened and ground to fine limits of squareness and parallelism.



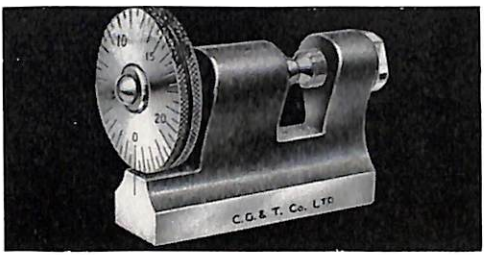


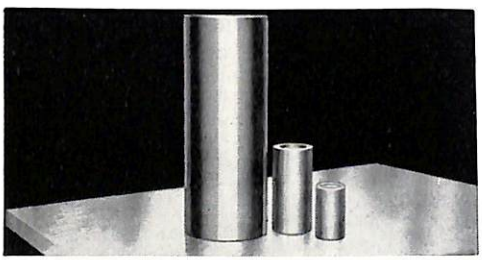
Work Locator

An ingenious, time saving machine shop accessory, making it possible to "pick-up" the form of a threaded component or the teeth of a roughed-out gear in relation to the tool or grinding wheel, without disturbing the setting of the producing machine.

Rolling Mill Micrometers

Sturdy accurate gauges for measuring plates and strip during continuous cold running.



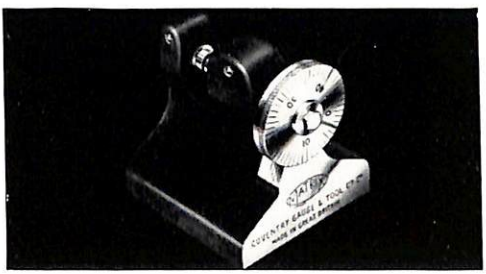


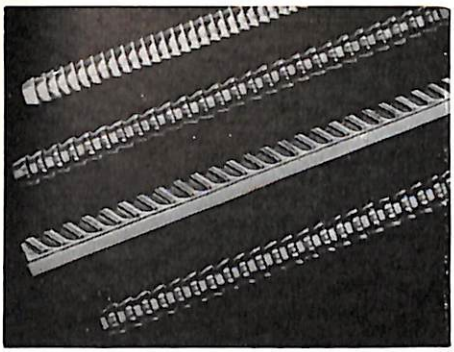
Cylindrical Squares

Obtainable in a range of convenient sizes. Accurately made to fine limits and guaranteed truly square.

Paper and Board Micrometer

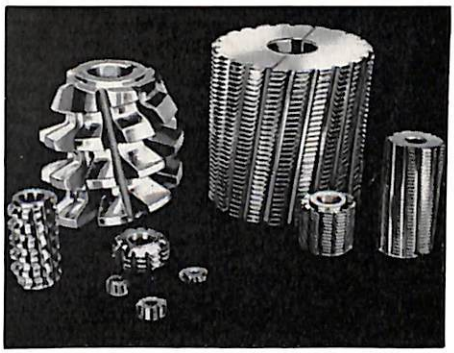
Measures accurately and with the greatest simplicity any thickness of stock from mill-board to rice-paper. Large dial calibrated in ·001" divisions. A boon to the Printing trade.





Broaches

This Company is one of the pioneers in the development of broach manufacture and broaching practice. The present high quality of "Matrix" Broaches is therefore the result of many years' experience. Our highly specialised staff of engineers are at all times ready to give reliable advice on the design and application of broaches.

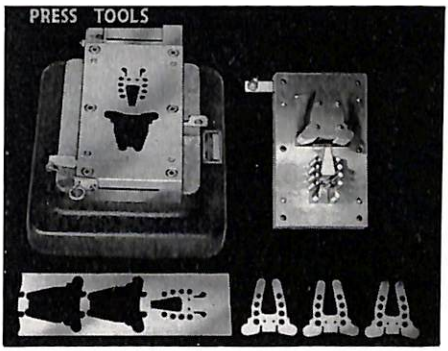


Hobs and Form Milling Cutters

With either cut or ground form made to B.S.I. Specification or customers' own requirements for special high precision work. Used extensively by leading manufacturers throughout the world.

Circular Thread Form Cutting Tools

These high precision tools are available in three groups of sizes for internal and external work and cover a wide range of pitches from 100 T.P.I. down to 2½ T.P.I. Appropriate Holders and Regrinding Jigs can be supplied.

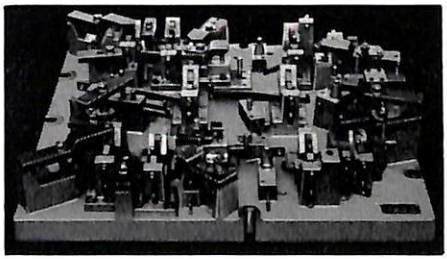


Press Tools

Designed and constructed to customers' special requirements, including Follow-on Tools, Compound Tools, Bending Tools, Drawing Tools and Combination Tools. Our specialised staff is ready to offer help and suggestions on all press tool problems.

Multi-Disc Clutches

Wherever the smooth transmission of power is required, there is a use for "Matrix" Multi-Disc Clutches. Wet and dry types are available either in single or duplex units. They have the minimum of working parts and are capable of carrying heavy load in relation to their size. Adaptable to most awkward and limited spaces.



Jigs and Fixtures

We are specialists in the design and manufacture of Jigs and Fixtures of every description. We maintain a staff of designers and skilled toolmakers for this highly specialised work and our thirty years' experience in Jig and Fixture manufacture is at your disposal.

INCHES TO MILLIMETRES.
FRACTIONS.

Inches.				m/m	Inches.				m/m
		1/64	·015625	3969			33/64	·515625	13·0969
	1/32		·03125	·7937		17/32		·53125	13·4937
		3/64	·046875	1·1906			35/64	·546875	13·8906
1/16			·0625	1·5875	9/16			·5625	14·2875
		5/64	·078125	1·9844			37/64	·578125	14·6844
	3/32		·09375	2·3812		19/32		·59375	15·0812
		7/64	·109375	2·7781			39/64	·609375	15·4781
1/8			·125	3·1750	5/8			·625	15·8750
		9/64	·140625	3·5719			41/64	·640625	16·2719
	5/32		·15625	3·9687		21/32		·65625	16·6687
		11/64	·171875	4·3656			43/64	·671875	17·0656
3/16			·1875	4·7625	11/16			·6875	17·4625
		13/64	·203125	5·1594			45/64	·703125	17·8594
	7/32		·21875	5·5562		23/32		·71875	18·2562
		15/64	·234375	5·9531			47/64	·734375	18·6531
1/4			·25	6·3500	3/4			·75	19·0500
		17/64	·265625	6·7469			49/64	·765625	19·4469
	9/32		·28125	7·1437		25/32		·78125	19·8437
		19/64	·296875	7·5406			51/64	·796875	20·2406
5/16			·3125	7·9375	13/16			·8125	20·6375
		21/64	·328125	8·3344			53/64	·828125	21·0344
	11/32		·34375	8·7312		27/32		·84375	21·4312
		23/64	·359375	9·1281			55/64	·859375	21·8281
3/8			·375	9·5250	7/8			·875	22·2250
		25/64	·390625	9·9219			57/64	·890625	22·6219
	13/32		·40625	10·3187		29/32		·90625	23·0187
		27/64	·421875	10·7156			59/64	·921875	23·4156
7/16			·4375	11·1125	15/16			·9375	23·8125
		29/64	·453125	11·5094			61/64	·953125	24·2094
	15/32		·46875	11·9062		31/32		·96875	24·6062
		31/64	·484375	12·3031			63/64	·984375	25·0031
1/2			·5	12·7000					

1·/1000

Ins.	m/m
·001	·0254
·002	·0508
·003	·0762
·004	·1016
·005	·1270
·006	·1524
·007	·1778
·008	·2032
·009	·2286

1·/100

Ins.	m/m
·01	·254
·02	·508
·03	·762
·04	1·016
·05	1·270
·06	1·524
·07	1·778
·08	2·032
·09	2·286

1"/10

Ins.	m/m
·1	2·54
·2	5·08
·3	7·62
·4	10·16
·5	12·70
·6	15·24
·7	17·78
·8	20·32
·9	22·86

UNITS.

Ins.		10	20	30
0		254·0	508·0	762·0
1	25·4	279·4	533·4	787·4
2	50·8	304·8	558·8	812·8
3	76·2	330·2	584·2	838·2
4	101·6	355·6	609·6	863·6
5	127·0	381·0	635·0	889·0
6	152·4	406·4	660·4	914·4
7	177·8	431·8	685·8	939·8
8	203·2	457·2	711·2	965·2
9	228·6	482·6	736·6	990·6

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MILLIMETRES TO INCHES.
UNITS.

	m/m	10	20	30	40	50	60	70	80	90
0		·39370	·78740	1·18110	1·57480	1·96851	2·36221	2·75591	3·14961	3·54331
1	·03937	·43307	·82677	1·22047	1·61417	2·00788	2·40158	2·79528	3·18898	3·58268
2	·07874	·47244	·86614	1·25984	1·65354	2·04725	2·44095	2·83465	3·22835	3·62205
3	·11811	·51181	·90551	1·29921	1·69291	2·08662	2·48032	2·87402	3·26772	3·66142
4	·15748	·55118	·94488	1·33858	1·73228	2·12599	2·51969	2·91339	3·30709	3·70079
5	·19685	·59055	·98425	1·37795	1·77165	2·16536	2·55906	2·95276	3·34646	3·74016
6	·23622	·62992	1·02362	1·41732	1·81103	2·20473	2·59843	2·99213	3·38583	3·77953
7	·27559	·66929	1·06299	1·45669	1·85040	2·24410	2·63780	3·03150	3·42520	3·81890
8	·31496	·70866	1·10236	1·49606	1·88977	2·28347	2·67717	3·07087	3·46457	3·85827
9	·35433	·74803	1·14173	1·53543	1·92914	2·32284	2·71654	3·11024	3·50394	3·89764

	m/m	100	200	300	400	500	600	700	800	900
0		3·93701	7·87402	11·8110	15·7480	19·6851	23·6221	27·5591	31·4961	35·4331
10	·39370	4·33071	8·26772	12·2047	16·1417	20·0788	24·0158	27·9528	31·8898	35·8268
20	·78740	4·72441	8·66142	12·5984	16·5354	20·4725	24·4095	28·3465	32·2835	36·2205
30	1·18110	5·11811	9·05513	12·9921	16·9291	20·8662	24·8032	28·7402	32·6772	36·6142
40	1·57480	5·51181	9·44883	13·3858	17·3228	21·2599	25·1969	29·1339	33·0709	37·0079
50	1·96851	5·90552	9·84252	13·7795	17·7165	21·6536	25·5906	29·5276	33·4646	37·4016
60	2·36221	6·29922	10·2362	14·1732	18·1103	22·0473	25·9843	29·9213	33·8583	37·7953
70	2·75591	6·69292	10·6299	14·5669	18·5040	22·4410	26·3780	30·3150	34·2520	38·1890
80	3·14961	7·08662	11·0236	14·9606	18·8977	22·8347	26·7717	30·7087	34·6457	38·5827
90	3·54331	7·48032	11·4173	15·3543	19·2914	23·2284	27·1654	31·1024	35·0394	38·9764

FRACTIONS

$\frac{1}{1000}$ mm.

m/m	Ins.
0·001	·000039
0·002	·000079
0·003	·000118
0·004	·000157
0·005	·000197
0·006	·000236
0·007	·000276
0·008	·000315
0·009	·000354

$\frac{1}{100}$ mm.

m/m	Ins.
0·01	·00039
0·02	·00079
0·03	·00118
0·04	·00157
0·05	·00197
0·06	·00236
0·07	·00276
0·08	·00315
0·09	·00354

$\frac{1}{10}$ mm.

m/m	Ins.
0·1	·00394
0·2	·00787
0·3	·01181
0·4	·01575
0·5	·01969
0·6	·02362
0·7	·02756
0·8	·03150
0·9	·03543

INTERNATIONAL INCH

1 INCH = 25·4 mm. EXACTLY
1 METRE = 39·3700787 INCHES

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